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STERILIZABLE ACCELEROMETER DEVELOPMENT PROGRAM

Bell Aerosystems Company
Cleveland, Ohio

30 January 1970

1.0 COVER

STERILIZABLE ACCELEROMETER
DEVELOPMENT PROGRAM

Report No. 60007-035

FINAL REPORT

30 January 1970

JPL Contract 951492

Prepared by: Bell Aerospace Company
4515 Superior Avenue
Cleveland, Ohio 44103

2.0 TITLE PAGE

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"This work was performed for the Jet Propulsion Laboratory, California Institute of Technology, as sponsored by the National Aeronautics and Space Administration under Contract NAS7-100."

3.0 TECHNICAL CONTRACT SCOPE OF WORK

Under this contract, the Bell Aerospace Company (BAC) was commissioned to perform an analysis of all materials as used in this company's Model VII miniature linear force balance accelerometer to determine by analytical means and by tests the influence on the accelerometer performance of changes in the characteristics of the materials with respect to thermal expansion, electrolytically induced corrosion, stresses, strains, etc., due to the thermal sterilization procedures at 135°C. This effort was directed toward achieving the post sterilization performance characteristics identified in Section 7.0 of this report.

Five sterilizable versions of the Model VII accelerometer and two sets of transformerless accelerometer pickoff electronics were fabricated and tested to determine performance characteristics after sterilization. Tests included vibration, shock and ethyline oxide compatibility, which were performed by JPL. In addition, the contract covered the design and fabrication of five sets of sterilizable proof mass assemblies using advanced laser beam welding techniques and one sterilizable proof mass using a monolithic beryllium pendulum structure.

4.0 ABSTRACT

Bell Aerospace Company (BAC) under the efforts funded by this contract endeavored to make their standard Model VII accelerometer thermally sterilizable. By sterilizable is meant that it be capable of meeting certain specifications and operate reliably after exposure to six sterilization cycles, each of 60 hours duration at 275° ambient temperature. The initial efforts were directed toward replacing those materials and components known to be unusable at the sterilization temperature and to replace them wherever possible from materials and components on the JPL preferred parts list.

The major technical consideration was determined to be the stability of the epoxy spring to pendulum joints under stresses induced by high temperature exposure. The various attempts at solution to this problem included substitution of new epoxies, a change in the pendulum material from aluminum to beryllium, and a replacement of the epoxy joint by laser beam welding of metal parts with electrically insulated surfaces

A parallel effort on the electronic assembly was to evaluate a BAC developed transformerless design in the sterilization environment.

5.0 TABLE OF CONTENTS

6.0 GLOSSARY

The terms used to define accelerometer parameters and their performance are as defined in EETC Report No. 30, titled "Standard Accelerometer Terminology" and prepared by Aerospace Industries Association (AIA).

7.0 TECHNICAL DISCUSSION

This section of the report will present the approach to making the Model VII accelerometer sterilizable and the results of the various investigations that were pursued in doing so, as well as the end results achieved.

For the purposes of this investigation, sterilizability is defined as the ability to operate without catastrophic failure and to perform within the performance criteria identified below, after exposure to six cycles of 64 hours duration during which the ambient temperature is 275°F. The required post sterilization accelerometer performance requirements are

(A)	Bias		±300 micro g maximum
(B)	Bias Stability		100 micro g 1 sigma
(C)	Scale Factor		1 ma/g ±10%
(D)	Scale Factor Stability	-	05% 1 sigma
(E)	Input Axis Alignment	-	±15 arc seconds
(F)	Input Axis Stability	-	30 arc seconds 1 sigma
(G)	Frequency Response	-	That of a critically damped second order system with a cutoff frequency not less than 300 Hz.

7.1 Model VII Operating Characteristics

The Bell accelerometer is a single axis, pendulous, flexure suspended, torque rebalance instrument. It is

equally applicable to analog and digital rebalancing techniques, and is presently being used in both types of applications.

The detection of acceleration on the instrument is accomplished by means of a capacitive pickoff and the rebalancing is effected by electromagnetic forces produced when current flows in the torquer.

The capacitive sensing system consists of two capacitance rings placed on each side of the proof mass. The proof mass is supported by two springs and is free to move along the input axis of the instrument. This is illustrated in Figure 1.

The capacitance rings are fixed with respect to the mounting base through an electrically insulating structure. The sensing system is completed by forming a capacitance bridge with two fixed capacitors. The proof mass and the capacitance rings are shown in Figure 2. The capacitance bridge is excited with a frequency that can vary from 8 KHz to 200 KHz depending on customer preference.

Any movement of the proof mass from the null position caused by acceleration on the mounting base will unbalance the bridge. The unbalance of the bridge will produce an amplitude modulation of the excitation frequency. The bridge unbalance signal is fed to a transformer and an amplifier integral to the accelerometer for proper signal conditioning.

The resulting signal is the error signal required by the external rebalancing circuitry.

The rebalance of the proof mass is accomplished by electromagnetic forces produced by passing current through the torquer. The proof mass is immersed in a high density magnetic field as shown in Figure 3.

The flux from the permanent magnets flows through the proof mass at right angles to the torquer coil windings. The torquer coil is connected to the external circuitry through the suspension springs which act as current carriers. A torquer coil current with the correct polarity produces a flux which reacts with the permanent magnet's flux to produce the force that tends to restore the pendulum to the null position.

This restoring current, produced by the rebalance electronics as a function of the error signal from the capacitance sensing system, can be in the form of an analog current or digital pulses.

Therefore, the accelerometer proof mass can be constrained in a high gain servo loop such that the acceleration force on the proof mass described by $f = ma$ is balanced by a force $f = LI_aB$ where:

f = force on pendulum proof mass

m = proof mass

a = acceleration

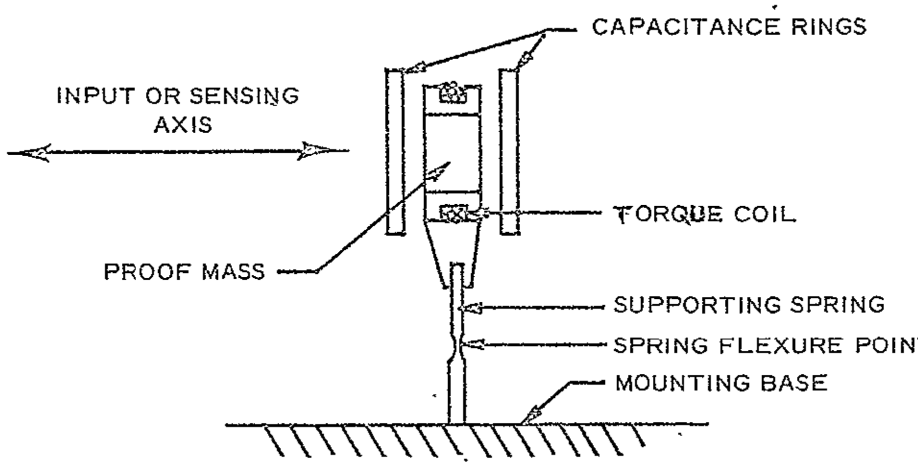


Figure 1

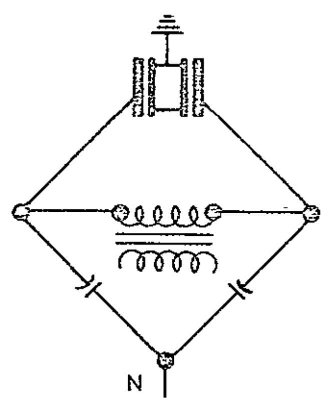


Figure 2

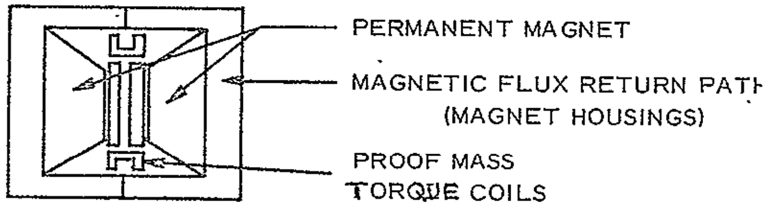


Figure 3

L = number of turns on proof mass torquer coil X mean circumference

B = magnetic flux density

I_a = torquer current

The variants in the force balance equation are a and I_a, thus current is a measure of acceleration and $I_a = \frac{ma}{LB}$.

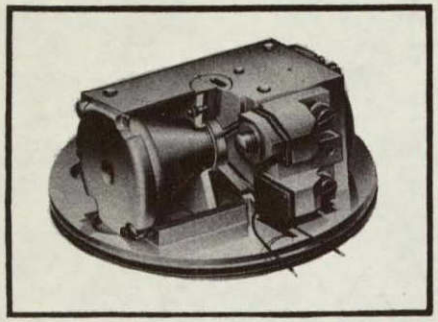
Since m and L are constants, the only other possible variant besides I , the rebalancing current, and a, the acceleration, is B, the magnetic flux density. Through years of experience, Bell has developed techniques to age and stabilize the permanent magnets so that instruments with very high scale factor stability result.

The accelerometer gets its damping from the eddy currents produced in the proof mass when it moves with respect to the permanent magnetic field. This movement induces currents in the proof mass which, in turn, produce flux that reacts with the permanent magnets' flux. This method of damping eliminates the need for filling the unit with fluid with its attendant sealing and contamination problems.

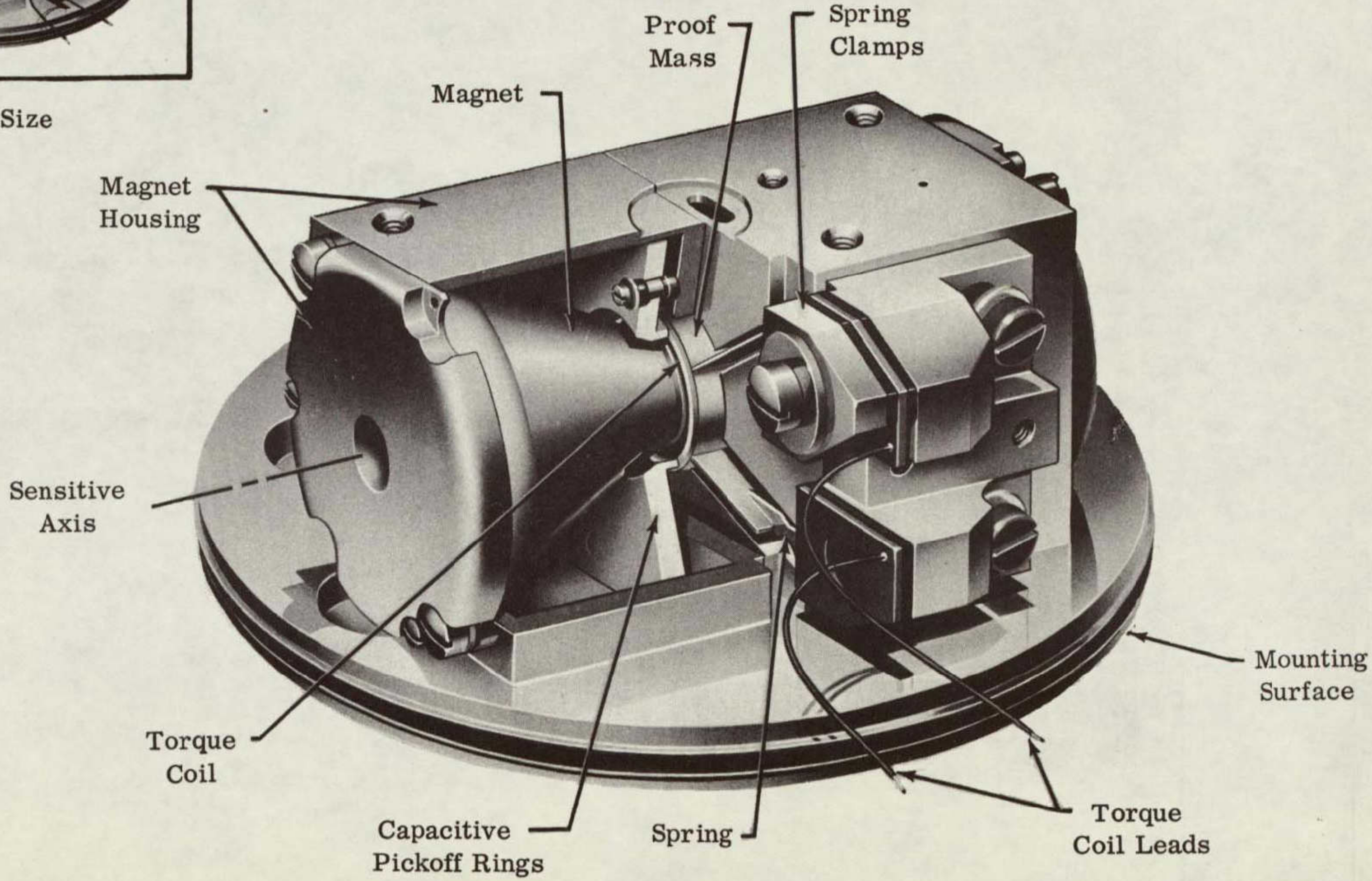
A cutaway view of the Model VII accelerometer to illustrate actual construction is shown in Figure 4.

Special design considerations include such features as:

1) Capacitive sensing offers the dual advantage of having infinite resolution and no coupling of electromagnetic



Actual Size



Bell Aerosystems Model VIIB Accelerometer

Figure 4

signals into the sensing system from the rebalancing currents.

2) Mechanical, magnetic and electrical symmetry assure identical characteristics of the instrument for positive and negative acceleration.

3) The magnetic path is closed around the pendulum to minimize flux leakage and to protect the transducer from external fields. Thus, several transducers can be mounted in close proximity.

4) A transistor stage is incorporated within the transducer housing to provide a low output impedance for the pick-off signal. Thus, compatibility with vehicle noise is achieved.

5) The cross-coupling caused by the proof mass moving from the nulled position can be held to a negligible value with the capacitance sensing system's infinite resolution, and the use of high gain rebalance electronics.

6) Acceleration sensing systems with a full scale output of 10^{-4}g and a threshold of less than 10^{-6}g have been built and flown in space vehicles. It is significant to note that the same spring suspension system that permits measurements and thresholds this low can also be used to measure accelerations as high as 150 g's and withstand

the rigorous vibrations and shock environments sustained during launch of the vehicle. The range and sensitivity is exclusively a function of the rebalancing electronics.

7.2 Preliminary Approach

The initial assessment of the task of sterilization had two separate considerations: the problem of modifying the instrument to eliminate any materials or parts that could cause catastrophic failure due to the sterilization temperatures and the modifications necessary to meet the sterilization performance requirements. Previous applications of the Model VII required storage of the instrument up to 200°F, but there was no previous experience at temperatures above this. For the purposes of the initial assessment, the mechanical and electronic assemblies were treated separately because of the different engineering disciplines involved.

In the case of the mechanical assembly, it was immediately recognized that some of the epoxies used had curing temperatures below 275°F. It was felt that exposing thes epoxies to temperatures above their curing temperatures would almost certainly produce deleterious effects on the bonds themselves or result in excessive outgassing which could contaminate the unit. Therefore, the pursuit of substitute epoxies was started early in the program.

The Electronic Assembly of the Model VII had components

that were not rated for use after exposure to 275°F; in addition, very little was known about the effects on the special pickoff transformer fabricated by Bell. Replacement of the electronic parts was guided by the JPL preferred parts list and work was initiated to redesign and test the transformer after sterilization early in the program.

The third area considered, and probably the most difficult technical task was the improvement of the post sterilization performance. In retrospect this was found to be the major problem. The expected magnitude of performance degradation was projected from performance established by a Model IIIB accelerometer (which is a similar but larger accelerometer than the Model VII) after exposure to lower storage temperatures than the sterilization temperature. A standard Model IIIB had previously been exposed to storage at 200°F for 120 hours. This environment was considered mild compared to the total sterilization temperature time of 360 hours at the 275°F temperature. The difference in duration was not considered significant but rather the difference in storage temperature. The bias bandwidth of the Model IIIB degraded from a typical worst case 250 ug's at lower storage temperatures (75°F) to approximately 800 ug's after the 200°F exposure. Additional data on the Model IIIB accelerometer (-5, -10 and -17A types) was accumulated by JPL during the Ranger and Mariner programs. JPL exposed 15 of these accelerometers

to +125°C for 24 hours. Two of these were exposed twice. While the temperature was lower than present day requirements and exposure time was shorter, results were significant, showing bias change as high as 1650 ug's. These early Model IIIB tests also indicated a marked improvement in their ability to withstand higher temperatures when a monolithic pendulum design was incorporated. An assumption was made that as a first approximation of the existing Model VIIB design, the bias bandwidth is proportional to the square of the soak temperature in degress Fahrenheit. This resulted in a projected bias bandwidth of 1800 ug's after exposure to 275°F. Specifically, it was anticipated that both the bias stability and uncertainty would be degraded and that to achieve the +300 ug's as the maximum bias bandwidth would present the major technical challenge; therefore, the greatest effort was directed to this performance parameter. The performance degradation of the other parameters, i.e. scale factor, axis alignment and frequency response, was not considered to be significant at this point.

The verification of the validity of the estimated bias bandwidth, after exposure to 275°F, was considered to be one of the most critical experimental steps to be taken early in the program. Fortunately, such an experiment was run by JPI personnel with two standard Model VII instruments shortly after the program started. The bias bandwidth of these Model

VII's after sterilization was found to be 1500 ug's. These test results confirmed the initial estimate.

The initial assessment of the cause of this large bias shift produced the opinion that the most suspect material was the epoxy used to attach the springs to the pendulum supports. Any degradation of this joint would manifest itself as a bias change. The primary requirement of this mechanical attachment of the springs to the pendulum is that it must provide an electrical insulation between the spring and coil form structure.

7.3 Standard Model VII Sterilization Experiments

Complete standard Model VII accelerometers and components were exposed to prolonged storage at the sterilization temperature. The parts were subsequently examined.

The significant observations from these experiments were as follows:

1) The metal parts were unaffected except that there was some slight discoloration, particularly on the nickel plated soft iron surfaces. No real significance was attached to this because it wasn't felt this would per se degrade performance and might, in fact, have been caused by outgassing of the non-metallic parts.

2) Deposits were observed in several places. The first type of deposit found was a smooth, white, transparent

and sticky substance. It was found on outer surfaces of the magnet housings and would not impair the performance of the accelerometer. It is believed to be a remainder of soldering flux, and that thorough cleaning would avoid its appearance.

The second type of deposit settled mostly on copper containing metal parts, giving them a shiny appearance. It did not appear on the brass capacitance rings contained inside of the magnet assemblies, which indicates that its source lies outside of the magnet assemblies. This deposit, too, could be due to remains of flux. It also would not impair the performance of the accelerometer.

The third type of deposit could, if buildup continued, lead to a catastrophic failure. It was white, opaque and granular. It was found mainly in the air gap of the magnetic flux path, namely on the I.D. of the magnet housing and on the O.D. of the aluminum coil form. It appeared mostly on that part of the I.D. of the magnet housing that is opposite to the coil windings of the pendulum. The I.D. of the coil form and the O.D. of the flux plates remained free of the deposit, the grain size of which was generally between .001 and .003 inches. In the area between the I.D. of the magnet housing and the O.D. of the torquer coil form, this was nearly enough to bridge the air gap. It is suspected that the deposit

originated from the FFA-2 epoxy applied to the torquer coil windings. A further type of deposit was observed in the same area as the white, opaque granulated deposit, namely, an extremely thin even coverage of light brown which did not appear to be rust. This deposit would not affect the accelerometer performance. From the color of the deposit, it was felt that its origin could be the Isonel type 155 magnet wire insulation.

3) The non-metallic parts had observable signs of deterioration. It was recognized that visual deterioration alone is not a valid criterion for the acceptance or rejection of a material. On the other hand, extensive analytical chemistry and laboratory work would have been beyond the scope of the program. For this reason, Bell made an effort to replace all existing materials not contained in JPL's preferred materials list, regardless of the degree of deterioration that was recorded.

7.4 Mechanical Assembly Analyses

The Mechanical Assembly's components were subdivided into metallic and non-metallic parts for the purpose of analysis and possible substitution of other materials. In most cases a simple substitution was considered, but, in the pendulum design, several different configurations evolved because here the considerations were more complex and, therefore, they are treated in a separate subsection of this section.

7.4.1 Metallic Materials Investigation

The investigation of the metal parts exclusive of the pendulum showed that the only suspect material was brass which is used for the capacitance rings. Whereas the other metal parts merely exhibited a slight discoloration, the brass capacitance rings had a slight outgrowth. This outgrowth is apparently normal for copper-zinc alloys when exposed to elevated temperatures. The zinc forms zinc-oxide crystals that protrude from the capacitance ring surface. This process is accelerated at elevated temperatures. The first approach to eliminating this problem was the application of a proper surface protection. This development encompassed two considerations:

1) The identification of an [illegible] protection procedure;
2) The establishment of a new assembly procedure for the magnet housing capacitance ring assembly to accommodate the surface protection procedure.

In considering protective coatings, the investigation first considered the following: Liquid Bright Gold #6854 and Liquid Bright Platinum #05 (products of the Hanovia Liquid Gold Division of Engelhard Industries) to be applied by brushing. The results were not satisfactory. After firing, the coating was found to be uneven and bright only in limited areas. Since even coating is essential to main-

tain the proper position of the pick-off surface after re-installation of the capacitance ring, these efforts were discontinued.

Next, a chromating process was applied rendering an even shiny surface which will readily accept 60/40 SN 60 solder.

Further, a process of electroless gold plating was tried. The chemicals were obtained from Technic, Inc. This process is designated as Oromerse, Immersion 24 KT Gold. According to information from the supplier, a coverage of 3 micro inches builds up in about 15 minutes. Further submersion adds only very little to the film thickness.

The chromated parts and the parts plated with Oromerse were subjected to temperature sterilization. The chromated parts were found to be discolored to a dull dark brown. The two capacitance rings treated with Oromerse appeared unaffected by temperature sterilization; their surfaces looked bright and shiny without any indication of discoloration or any sign of outgrowth. The application of the protective coating necessitated introduction of new steps in the accelerometer assembly procedure.

In the magnet housing-capacitance ring assemblies of the standard Model VII accelerometers, the distance between the pickoff surface of the capacitance ring and the reference surface of the magnet housing is controlled within ± 50 micro

inch. In order to obtain this high accuracy, the pickoff surface of each capacitance ring is machined after the capacitance ring is installed in the magnet housing. Removal of the capacitance ring from the magnet housing was felt to be mandatory for the process of surface protection. Care had to be taken to assure that in the process of re-assembly, the pickoff surface of the capacitance rings was restored accurately to its position after machining. A procedure to obtain this result has been established: the three jewel washers used as spacers between the capacitance ring and the magnet housing are bonded to the magnet housing, e.g., by means of an epoxy, so that their position does not change when the capacitance ring is removed and reinstalled.

7.4.2 Non-Metallic Materials Investigation

The investigation of the non-metallic parts exclusive of the pendulum showed that several material substitutions were equired. The materials as well as their usage in the instrument and the substitution made are identified below:

TUF-ON 747-S Varnish: This material was used to cover the exposed surface of the magnets.

Replaced by: 828/Z

#5 Electrical Tape (3M): This material was used to cover through holes in the magnet housings to prevent penetration of dust particles.

Replaced by: #7300 Mystic Tape

Nylon: This material was used for spacers between the magnet housings and the top cover.

Eliminated

Formvar Insulated Wire: This wire was used to connect the ends of the coil windings to the spring tabs.

Replaced by: Heavy Isonel 200

Locktite, Grade A: This material was used to secure s screws, either in the thread or at the head, or both.

Replaced by: LCA-49

Epon 828/D (Shell): This material was used to attach the flux plates to the magnets and to bond the Diamonite insulators to the base plate and to the spring clamps.

Replaced by: 828/Z

Polyolefin: RNF 100 heat shrinkable sleeving was shrunk over the capacitance leads and beryllium copper tubes soldered to the capacitance rings.

Replaced by: Kynar 3/64

Isonel Wire Type 155: AWG #44 wire was used to make the coil assembly.

Replaced by: Heavy Isonel 200

7.4.3 Pendulum Configuration

Previously it was identified that the major instrument vulnerability to sterilization was in the epoxy joint be-

tween the springs and the pendulum assembly. Because the elimination of this vulnerability took several forms, the pendulum is treated in a separate subsection.

A second problem area encountered in the pendulum was in the method of attachment of the torque coil to the pendulum in the standard Model VII. This will be discussed first and the problem identified in the above paragraph subsequently.

7.4.3.1 Torquer Coil - Pendulum Bobbin Analysis

In the standard Model VII pendulum design, the torquer coil winding was inserted into a groove. The groove was located on the inside surface of the cylindrically shaped pendulum frame. For this application, the FFA-2 epoxy was chosen because it provided self-support for the pre-fabricated coil assembly, yet it also maintained a flexibility for properly forming the coil during the insertion into the inner groove of the coil form. The curing temperature of FFA-2 is about 200°F. Exposure to 275°F is undesirable because of its poor outgassing characteristics, and because dimensional deformation and creep is unavoidable. This would result in shifts or movement of the torquer coil windings on the pendulum structure, which, in turn, could adversely affect the bias and scale factor performance.

It was felt that to eliminate this possible error

source the usage of semi-rigid epoxy should be avoided. Therefore, Bell introduced a new pendulum design with grooves machined on the outside of the cylindrical surface of the pendulum bobbin. This design permitted winding the coil directly on the pendulum structure and was secured with epoxy 828/Z. This design should result in a better form stability and the temperature sterilization should produce no creep effect. This new pendulum design considerably helped to achieve the good scale factor stability of the accelerometers. Test data subsequently indicated the scale factor performance to be well within goal requirements of 0.05% one sigma in four out of five cases.

7.4.3.2 Pendulum to Spring Bonding Analysis

Because of the limitations recognized in the epoxy (LCA-4/BA-9) used in this joint in the standard Model VII, an investigation into possible substitutes was pursued. The materials considered are as presented below:

<u>BU-120D</u> - Pittsburgh Plate Glass Company
<u>Ablecast 147-1</u> - The Ablestik Adhesive Co.
<u>EC-1469</u> - Minnesota Mining & Mfg. Company
<u>EC-2258</u> - Minnesota Mining & Mfg. Company
<u>2850 FT/11</u> - Emerson & Cummings
<u>LCA-4/BA-9</u> - Bacon Industries (distributed by the Ablestik Adhesive Co.)

The most reliable method of evaluating these materials would have been to build up and test complete accelerometers with each of the materials. Since this was impractical from a time and cost point of view, it was decided that a series of experimental tests on the materials would provide some significant indications of their applicability and might even identify one as being the optimum choice.

The following types of tests were performed:

1) Test to determine heat distortion temperature;
2) Wetting and bonding test on surfaces of Aluminum 3003 and of Berylco 25 materials, including peeling tests;
3) Shear tests under normal temperature conditions and after temperature sterilization.

At the conclusions of these tests all but two epoxies were eliminated from further evaluation. These were:

EC-2258 and

Ablecast 147-1.

These materials were tested in a functional accelerometer and have shown improvement compared to standard accelerometers.

However, EC-2258 turned out to be electrically conductive epoxy because of its aluminum powder filler. So this material had to be discarded as a possible substitute. The epoxy Ablecast 147-1 remained the only poss-

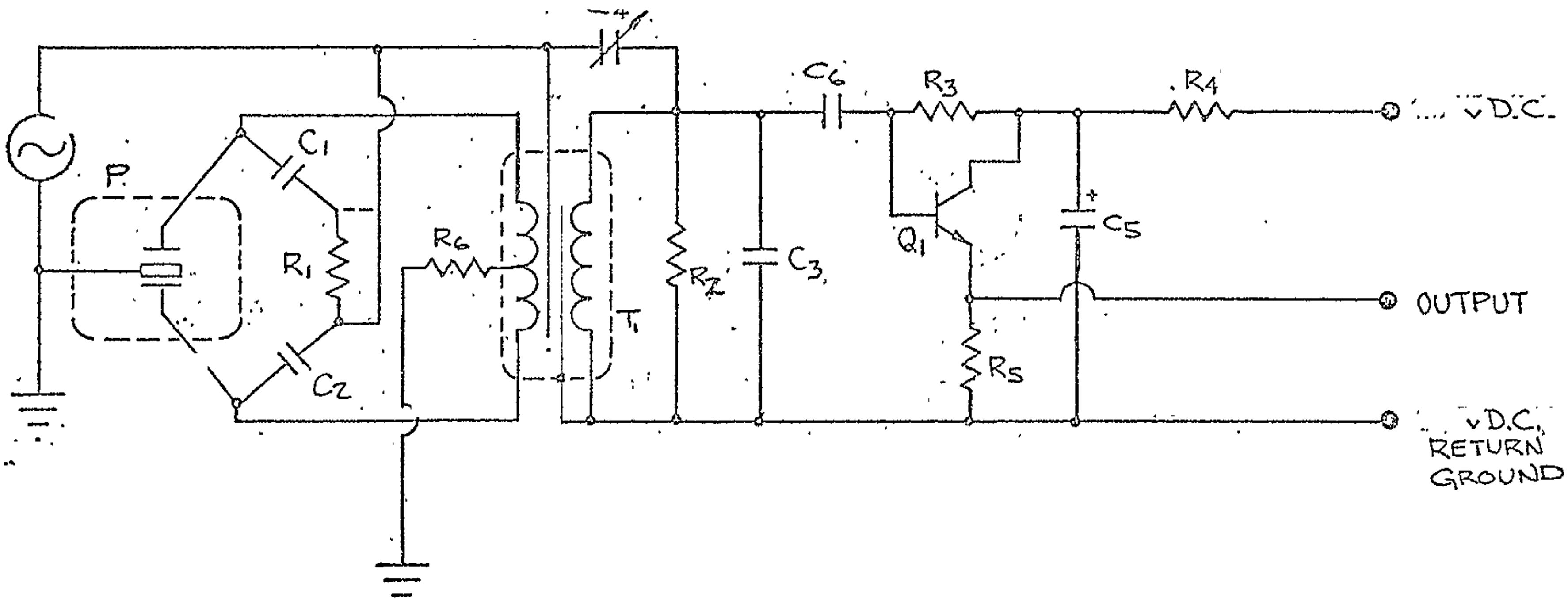
ible choice for the replacement of LCA-4/BA-9 compound to assure improved bonding between the spring tab and pendulum support, and it was used on all accelerometers tested.

7.5 Electronic Assembly Analysis

The basic principles governing the design of the standard Model VII electronics were also applicable to the development of a sterilizable electronic assembly. (See Figure 7.5, page 25a for the Schematic Diagram.) The main efforts were directed toward the definition of the sterilizable electronics configuration.

In order to meet the design goals outlined by the JPL specification, a set of performance requirements was established. The electrical parameters described below characterize and control the function of this assembly:

Excitation Frequency	192 Kc
Input Impedance	-j 8.0 Kohms or greater
Pickoff Scale Factor (output scale factor	40 ± .5mv/mr
Phase Angle	90° ± 10° heading with header pin "H" down
Maximum Power Consumption	.125 watts
Noise	1.0mv
Output Impedance	500 ohms
Quadrature	1 mv.



SCHEMATIC DIAGRAM

Figure 7.5

The electronic assembly comprises three major components:

1) The two capacitors constituting the fixed elements of the capacitance bridge and a variable capacitor for resultant null adjustment;

2) the pickoff transformer;

3) the preamplifier.

The part selection for the sterilizable configuration was governed by performance and reliability considerations and, as far as possible, by the JPL Preferred Parts List (PPL).

7.5.1 Bridge Capacitors

The fixed capacitors constitute the upper arms of the capacitance bridge. Their temperature drift characteristics and stability vs. time behavior are very important because these parameters control the electrical null performance which has a significant effect on bias stability.

The quality and reliability of these components was upgraded by selecting the Corning Glass capacitor CYFR and by purchasing in accordance with specification J951 inspection level B. This device has a fused monolithic construction sandwiched between the two conductive elements. A glass to metal seal terminates the internal structure and provides a complete environmental protection for the critical elements.

The temperature coefficient is approximately 140 $\pm$ 25 PPM/C° The devices selected will not deviate from a predetermined temperature characteristic by more than 5 PPM/C°

The purpose of the variable capacitor is to assure that the absolute value of the null bias does not exceed 100 ug before final sealing of the instrument. This is achieved by trimming the variable capacitor. This component was specifically designed for this application per Bell specification control drawing 26-01011-1. It is manufactured by J.F.D. Electronics of New York.

7.5.2 The Pickoff Transformer

The transformer is designed to transmit the error signal from the output of the capacitance bridge circuitry into the preamplifier. It is important that the signal transmission be achieved without introducing undesired loading on the bridge and without any effect on bridge balance conditions. To minimize the bridge loading, the transformer is tuned to parallel resonance at the operational frequency of 192 KHz. To eliminate any bridge balance influence, the unbalance and drift of the stray capacitances of the transformer measured from primaries to ground must cause only negligible secondary effects. This is achieved by the layout and construction of the transformer. The quality of the transformer, in particular the magnitude of the stray capacitances and their stability in time and temperature, was assured by separate shieldings provided for both the primary and secondary windings Furthermore;, the device is case in a carefully selected potting compound. The quality of the transformer is assured by evaluation of two sets of test data. The transformer is

tested first before potting and, secondly, after potting and temperature cycling. These tests assure that the transformer performs in accordance with the specification requirements listed below:

SPEC. PARAMETER	BEFORE POTTING	AFTER POTTING
1. Primary Inductance	11 - 13 mh	11 - 13 mh
2. Q at 180 KHz (Pri)	>12.0	>10.0
3. Primary Distributed Capacitance	<30.0 pf	<35.0 pf
a) with primary shield to lead A	<30.0 pf	<35.0 pf
b) with primary shield to lead B	<30.0 pf	<35.0 pf
4. Secondary Inductance	.5 - 3.5 mh	2.5 - 3.5 m
5. Secondary Distributed Capacitance	<75.0 pi	<80.0 pf
6. Q at 180 KHz (sec)	>12.0	>10.0
NOTE: Capacitance difference between 3a and 3b must be less than 3.0 pf	<3.0 pf	<3.0 pf

7.5.3 The Preamplifier

The preamplifier is a high input and low output impedance device. It is a single stage a-c amplifier, an emitter follower with unity gain.

The following sections describe the design considerations applied for the part selection of this component.

C_3 - Tuning Capacitor

This capacitor is used to tune the primary of the pickoff transformer to parallel resonance. This tuning capacitor must be stable. The capacitor selected is Corning Glass CYFR per specification J951 inspection level B, which appears on the JPL Preferred Parts List.

R_1, R_2, R_3, R_4, Fixed Resistors

R_3 and R_4 are used primarily for D.C. Biasing; R_1 is a quadrature resistor; R_2, a bandwidth controlling resistor. These resistors are all high Rel type which conform to MIL-R-55182A inspection level B. They are also on the JPL Preferred Parts List.

The resistor selected is a metal film type XLT manufactured by ITC. It meets the specification as outlined in MIL-R-10509D and also meets all the circuit requirements, wattage, stability, and the predicted failure rates at a 60% confidence level. From a packaging point of view, it also has the proper physical size.

Decoupling Capacitor C_5

The capacitor selected for this is a Kemet 1.0 ufd rated at 50 VDC (Type KG).

Mfg. Part Designation is: KGLJ50KMS similar to that which appears on the JPL Preferred Parts List. MIL Part No. CSR136105KP per MIL-C-39003/1.

Transistor

An NPN930 transistor was selected because of its proven reliability and because it appears on the JPL Preferred Parts List.

Resistor Feedback R_5

The resistor is a molded composition resistor procured from Ohmite or Allen Bradley, type RCR07G, which meets and is certified to the specification outlined in MIL-R-39008 (RCR07, RCR20). The basic reason for the selection of the component is its small size and high ohmic value. This part is similar to the 1/4 watt carbon composition resistor found on the JPL Preferred Parts List.

Resistor Bleeder R_6

The selection of this particular type, RCR07 per MIL-R-39008 (RCR07, RCR20), was made primarily for its small physical size in conjunction with the high ohmic value requirement.

7.6 Sterilizable Accelerometer Configuration Summary

The following tables compare component parts and materials used in the Sterilizable Accelerometer which are different from those of a standard Model VIIB Accelerometer. Blanks under the "Sterilizable" Configuration indicate the material or part was not used. The reason for the elimination of the material or part is given in the "Use" column.

(7.6) COMPARISON OF MATERIALS/COMPONENTS

Final Assembly

Standard Model VII Accelerometer Material/Parts	Supplier	Sterilizable Mod. VII Accelerometer Material/Parts	Supplier	USE
#5 Scotch Brand Electrical Tape	3M Co.	#7300 Mystic Tape	The Borden Chem. Co.	Taping down of torque coil and ground leads
Locktite Grade A (10-1)	American Sealants Co.	LCA-49/BA 9 Frozen Adhesive	Shell Chemical Co. (Ablestik)	To secure screws
Nylon Spacer				Spacer was eliminated due to design change on all accelerometers
Adhesive (on back of Id. label)	Bradley Co.			Id. label was eliminated (fell off at 275°F); Mounting base engraved instead
1015 Flux	Kester Solder Co.	135 Flux	Kester Solder Co.	Sealing of instrument
#20 Tube Teflon				To guide leads in base; Eliminated - used only with thermistor temp. compensated accel.
Coating of Instrument	Magna Coating & Chem. Corp.			Coating of instrument; Eliminated as it may outgas in temp.; our standard nickel plating will be used as protective coating.

COMPARISON OF MATERIALS/COMPONENTS

Magnet Assemblies

Standard Model VII Accelerometer Material/Parts	Standard Model VII Accelerometer Supplier	Sterilizable Mod.VII Accelerometer Material/Parts	Sterilizable Mod.VII Accelerometer Supplier	USE
RNF 100 1/16 heat shrinkable sleeving	Rayclad Tubes Inc.	Kynar 3/64 heat shrinkable sleeving	Rayclad Tubes Inc.	Support of capacitance leads at cap. ring
#828 Epon Resin Cement with Curing Agent "D"	Shell Chemical Co. (Ablestik)	#828 Epon Resin Cement with Curing Agent "Z"	Shell Chemical Co. (Ablestik)	Bonding of flux plate to magnet
"Tuf-On" 747-S	Brooklyn Paint & Varnish Co.	#828 Epon Resin Cement with Curing Agent "Z"	Shell Chemical Co. (Ablestik)	Sealing of Magnet surface
#5 Scotch Brand Electrical Tape	3M Co.	#7300 Mystik Tape (Glass cloth, thermo setting)	The Borden Chem. Co.	Covering of openings in magnet assembly
Locktite Grade A (10-1)	American Sealant	LCA-4/BA 9 Frozen Adhesive	Shell Chemical Co. (Ablestik)	Securing of capacitance rings holding s[illegible]

COMPARISON OF MATERIALS/COMPONENTS

Torque Coil Assembly

Standard Model VII Accelerometer Material/Parts	Supplier	Sterilizable Mod. VII Accelerometer Material/Parts	Supplier	USE
Heavy Isonel Type 155 #44 AWG Wire	Hudson Wire Co.	Heavy Isonel Type 200 #44 AWG Wire	Hudson Wire Co.	Coil Winding
#828 Epon Resin Cement w/Curing Agent "D"	Shell Chemical Co. (Ablestik)	#828 Epon Resin Cement w/Curing Agent "Z"	Shell Chemical Co. (Ablestik)	To hold windings to coil form; to bond spring insulation to baseplate & clamps
Thermester L Magnet wire or equiv. #42 AWG	Hi Temp Wire Inc.	Heavy Isonel Type #200 #42 AWG wire	Hudson Wire Co.	Wire from spring to coil
XR 875 Silicone Varnish	Dow Chemical Co.			Coating of coil form (replaced by heavy anodizing of form - change in all accels.
Xylene $(CH_3)_2$	Mallinckrodt Chem. Works			Dilution of XR 875 Silicone Varnish.
1015 Flux	Kester Solder Co.	Neutral Flux in core of 60/40 SN60 solder	Kester Solder Co.	Soldering leads
LCA-4/BA9 Froze Adhesive	Bacon Industries	Ablecast 147-1	Ablestik	Third fill of spring-support bond
FFA-2 Frozen Epoxy Resin Cement with BA-6 Activator	Bacon Industries	#828 Epon Resin Cement w/Curing Agent "Z"	Shell Chemical Co. (Ablestik)	To bond torque coil windings together

COMPARISON OF MATERIALS/COMPONENTS

Transformer Assembly (potted)

Standard Model VII Accelerometer Material/Parts	Standard Model VII Accelerometer Supplier	Sterilizable Mod.VII Accelerometer Material/Parts	Sterilizable Mod.VII Accelerometer Supplier	USE
#2651 MM Stycast with Catalyst #11	Emerson & Cummings	#2850 FT Stycast with Catalyst #11	Emerson & Cummings	Encapsulation of transformer
#27 Tape, glass cloth, thermosetting	3M Company	#7020 Mystic Tape (glass cloth, thermosetting)	The Borden Chem. Company	Securing of leads befo[illegible] encapsulating transformer; protecting and isolating transformer windings and shields.
Grade Ht, Code 13 #40 AWG wire	Hi-Temp Wire, Inc.	Heavy Isonel Type 200 #40 AWG wire	Hudson Wire Co.	Transformer windings
Grade HS, Thermalon #30 AWG wire	Hi-Temp Wire, Inc.	Heavy Isonel Type 200 #40 AWG wire	Hudson Wire Co.	Leads attached to shields

COMPARISON OF MATERIALS/COMPONENTS

Electronic Assembly

Standard Model VII Accelerometer Material/Parts	Standard Model VII Accelerometer Supplier	Sterilizable Mod.VII Accelerometer Material/Parts	Sterilizable Mod.VII Accelerometer Supplier	USE
Transformer Ass'y (potted)	Bell 26-01213-3	Transformer Ass'y (potted)	Bell 26-01523-1	Center tap added; Outer shield added.
C_2 Capacitor 9.1 pf $\pm$ 5%	Corning Glass Spec J 950 CYFR 10-9 RIJ	C_2 Capacitor 9.1 pf $\pm$ 5%	Corning Glass Spec J 951 CYFR 10-G 9 RIJ	Bridge Capacitor (fixed)
C_1 Capacitor 24 pf $\pm$ 5%	Corning Glass Spec J 950 CYFR 10-240J	C_1 Capacitor 24 pf $\pm$ 5%	Corning Glass Spec J 951 CYFR 10-G 240J	Bridge Capacitor (fixed)
C_1 & C_2 Capacitors as possible substitutes from 10 - 22 pf	Corning Glass Spec J 950 CYFR 10-100J to 220J	C_1 & C_2 Capacitors as possible substitutes from 10 - 22 pf	Corning Glass Spec J 951 CYFR 10G 100J to 220J	Possible substitutes for C_1 and C_2 Bridge capacitors
C_4 Capacitor 240 pf $\pm$ 5%	Corning Glass Spec 950 CYFR 10-241J	C_4 Capacitor 240 pf $\pm$ 5%	Corning Glass Spec J951 CYFR 10G 241J	Coupling Capacitor*
C_5 Capacitor 1 uf $\pm$ 10%	Kemet CSR 13G 105 KP	C_5 Capacitor 1 uf $\pm$ 10%	Sprague 350 D105 x 9035 -A-2	Noise Suppression Capacitor - alternate used
R_4 Resistor 1.96 KΩ $\pm$ 1%	IRC RNR 55C 1961 FR	R_4 Resistor 499Ω + 1%	IRC XLT RNR 57C 4990 FS Alt: MEPCO series FH	Change from 1/10 watt rating to 1/8 watt rating and high reliability call out added
R_5 Resistor 2.15 KΩ $\pm$ 1%	IRC RNR 55C 2151 FR	R_5 Resistor 18.2 KΩ $\pm$ 1%	IRC XLT RNR 57C 1822 FS. Alt: Mepco Series FH	Change from 1/10 to 1/8 watt rating & high rel. call out added

* Change in Manufacturer's designation - part is same

COMPARISON OF MATERIALS/COMPONENTS

Electronic Assembly (cont.)

Standard Model VII Accelerometer Material/Parts	Standard Model VII Accelerometer Supplier	Sterilizable Mod.VII Accelerometer Material/Parts	Sterilizable Mod.VII Accelerometer Supplier	USE
R_1 Resistor from $49.9\Omega \pm 1\%$ to $1000\Omega \pm 1\%$	IRC RNR 55C	R_1 Resistor from $49.9\Omega \pm 1\%$ to $1000\Omega \pm 1\%$	IRC XLT RNR 57C Alt: Mepco Series FH	Change from 1/10 watt rating to 1/8 watt rating and high reliability call out added
22 MegΩ Resistor 2 pieces	Ohmite LIDSM	22 MegΩ Resistor 1 piece	LIDNU	Change from 1/4 watt & $\pm$ 10% resistance tolerance resistor to 1/8 watt & $\pm$ 5% resistance tolerance resistor.
#828 Epon Resin Cement w/Curing Agent "D"	Shell Chem. Co. (Ablestik)	#828 Epon Resin Cement w/Curing Agent "Z"	Shell Chem. Co. (Ablestik)	Bonding of boards together; bonding of transistors & variable cap. to boards, and spacers to bracket
Locktite Grade A (10-1)	American Sealants Co.	LCA-49/BA 9 Frozen adhesive	Shell Chem. Co. (Ablestik)	Securing of nuts to bracket

7.7 Testing of First Design Sterilizable Accelerometers. (Serial Nos. 657, 659 and 660)

The sterilizable accelerometers were evaluated in accordance with requirements of the JPL Statement of Work and the testing was governed by the following procedure:

A. Calibration and adjustment prior to initial testing;

B. Initial Testing

1) Measure and record bias, scale factor and input axis alignment at room temperature and at the temperatures of 50°C (122°F), 65°C (149°F) and 80°C (176°F).

2) Measure and record frequency response at room temperature and at 80°C (176°F)

C. Repeat Item B.1. five times over a period of not less than ten calendar days to establish a reference base for the following tests.

D. Submit accelerometer to sterilization cycle.

E. Measure and record the shift of the parameters determined in B as a result of thermal sterilization.

F. Repeat the sterilization procedure and the parameters shift test for a total of six cycles.

One sterilization cycle consisted of a temperature exposure of 135°C (275°F) for a period of not less than 60 hours. The rate of rise and fall of the temperature was controlled to be 19°C/hr. The accelerometer was not operated during the thermal cycle.

From the collected test data, the following performance parameters were evaluated:

1. Bias
2. Bias stability
3. Scale factor absolute
4. Scale factor stability
5. Input axis alignment
6. Input axis stability
7. Frequency response

7.7.1 Test Data

The following curves and tables are a summary of bias, scale factor and misalignment after exposure to a number of sterilization cycles.

Serial numbers 657, 659 and 660 were each subjected to 12 sterilization cycles. The first six cycles were considered as conditioning and, as can be seen on the bias and scale factor curves, no return readings were recorded on S/N's 657 and 660 during the six conditioning cycles. On S/N 659, return readings were recorded after each of the 12 cycles.

All sterilization testing was performed with the accelerometer base in the horizontal position so that input axis orientation would be random. All return points of Bias and Scale Factor were taken at room temperature and several

:adings were taken to insure that a stable condition had been reached. _he initial reference point on each curve is the final reading of the ten day stability test (data show~ in Appendix 10.0).

The tables show change in bias, scale factor and misalignment after subjection to the sterilization cycle Δ_{mean} is the arithmetic average of the changes; $\Delta_{1\sigma}$ is th one sigma value of the changes. It should again be noted that no readings were taken on S/N's 657 and 660 during conditioning cycles.

7.7.2 Test Results

The results of testing on S/N's 657, 659 and 660 at Bell and S/N 656 at JPL all showed bias changes in excess of 1000 ug, while scale factor and misalignment were within the requirements. These results indicated that additional design changes would have to be incorporated to achieve better bias stability with temperature. Section 7.8 discusses the changes.

SUMMARY OF TEST RESULTS ON ACCELEROMETER S/N 657

Sterilization Cycle Number	1	2	3	4	5	6	7	8	9	10	11	12	△ mean	△ 1σ
Bias Change (ug)							-1192	1769	384	-1654	1483	-1408	-103	1388
Scale Factor Change (PPM)							70	147	-30	13	81	46	55	55
Misalignment Angle Change (sec)							-5	-2	5	-1	2	-5	-1	3.6

SUMMARY OF TEST RESULTS ON ACCELEROMETER S/N 660

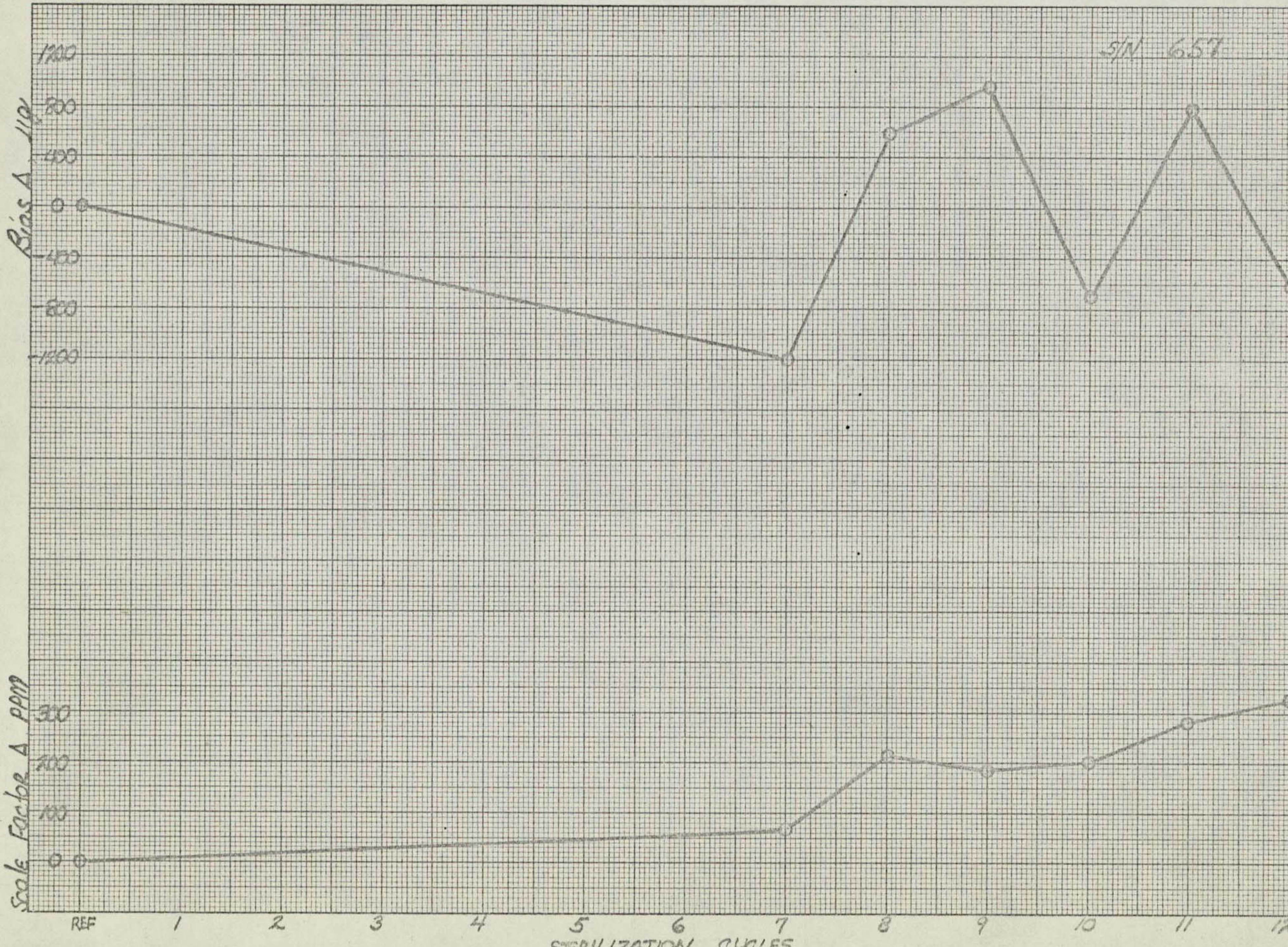
Sterilization Cycle Number	1	2	3	4	5	6	7	8	9	10	11	12	△ mean	△ 1σ
Bias Change (ug)							-2518	505	874	-640	2526	-1621	-146	1666
Scale Factor Change (PPM)							133	130	-3	-40	+98	+40	60	66
Misalignment Angle Change (sec)							-5	+2	-3	-2	0	2	-1	2.6

SUMMARY OF TEST RESULTS ON ACCELEROMETER S/N 659

Sterilization Cycle Number	1	2	3	4	5	6	7	8	9	10	11	12	Δ_{mean}	$\Delta_{1\sigma}$
Bias Change (ug)	-789	-60	1263	-649	640	611	-121	85	325	2319	-1199	448	239	907
Scale Factor Change (PPM)	662	-82	-34	-94	8	-385	59	-44	31	-77	2	-25	2	227
Misalignment Angle Change (sec)		0	3	-5	11	-11	14	-2	3	10	-8	4	2	7.6

Sterilization Cycle Number														
Bias Change (ug)														
Scale Factor Change (PPM)														
Misalignment Angle Change (sec)														

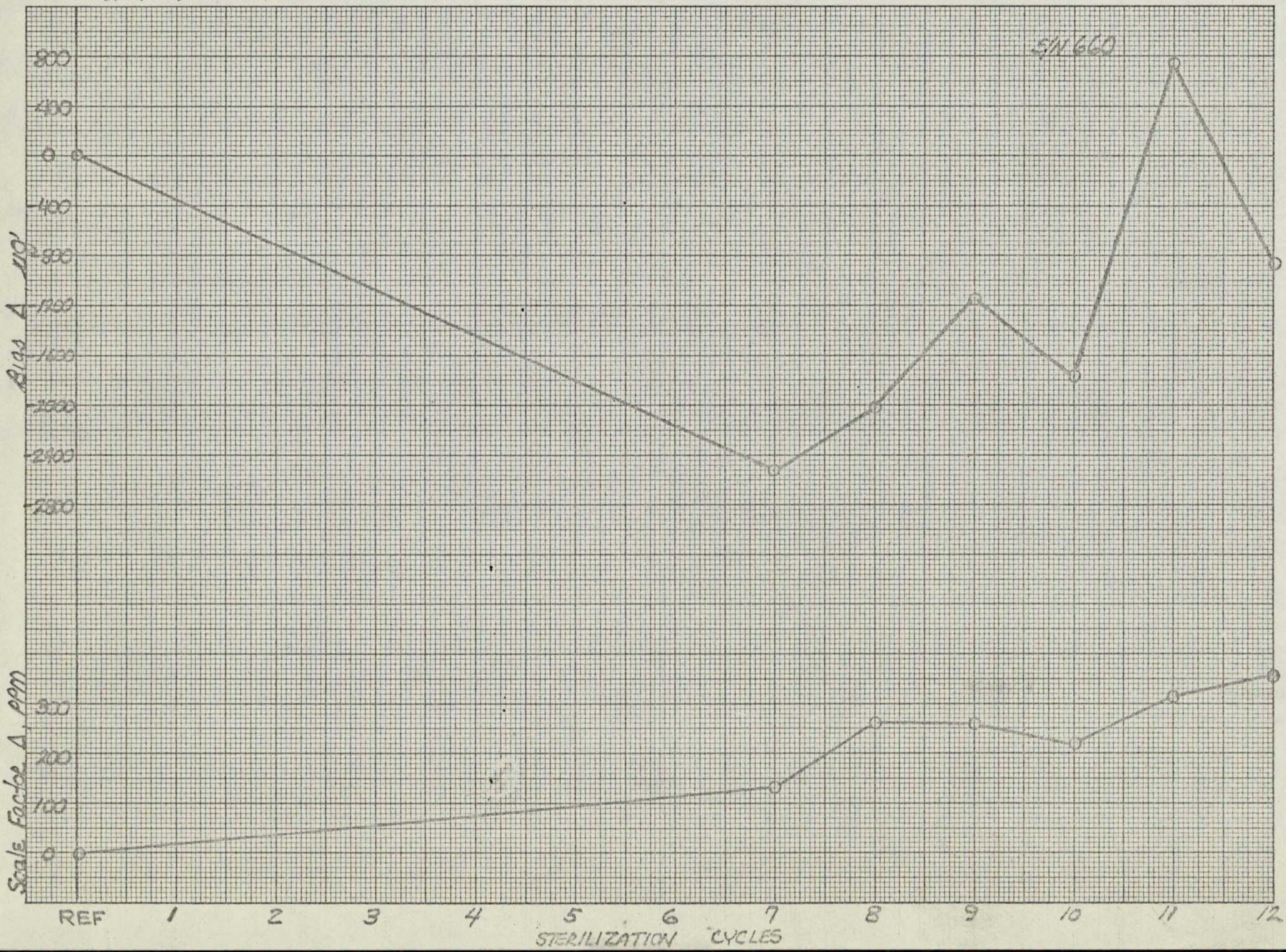
Bell Model VIIB-16 Accelerometer



KEUFFEL & ESSER CO.

(7.7.1)

Bell Model VIIB-16 Accelerometer



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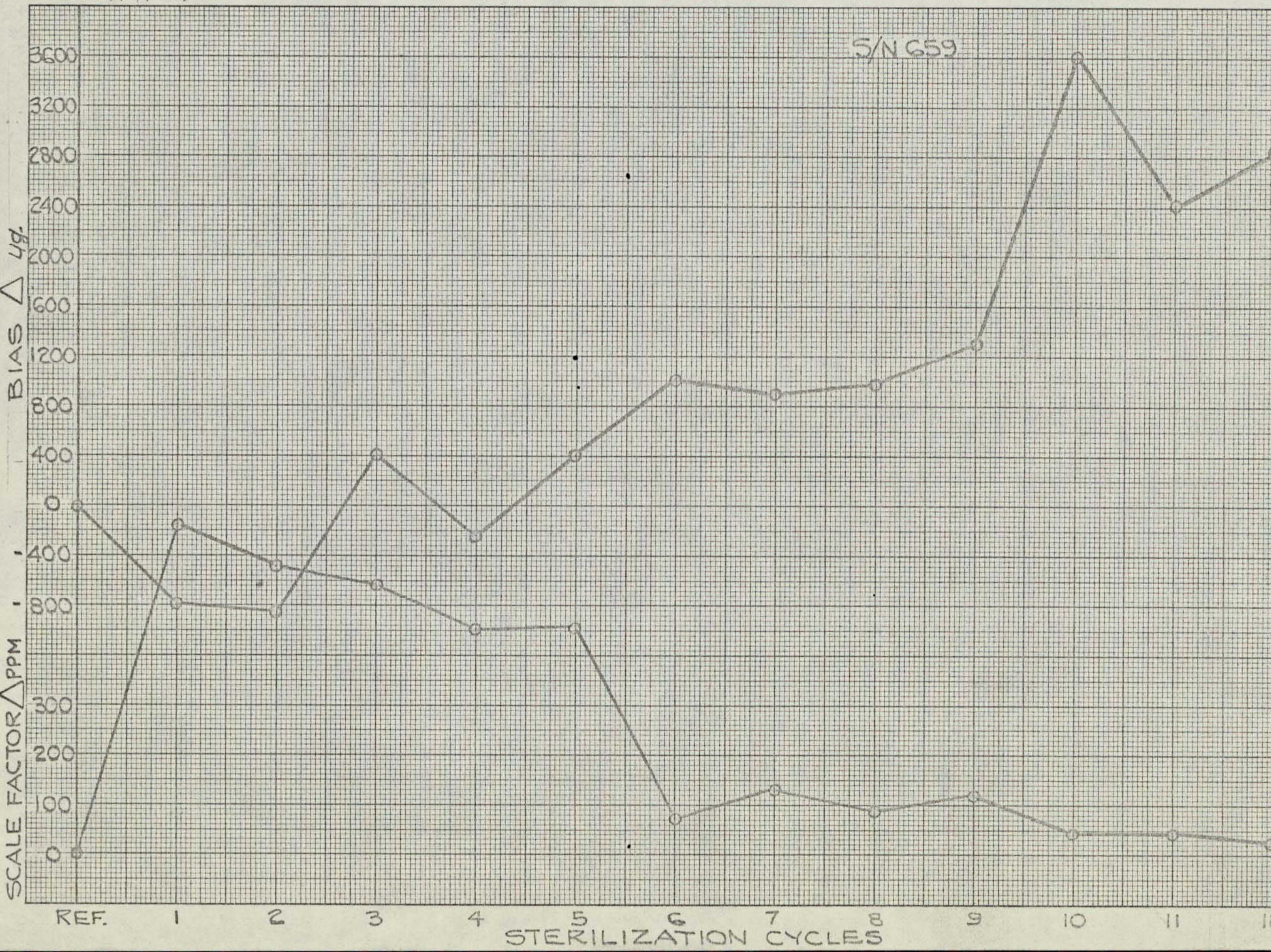
Bell Model VIIB-16 Accelerometer



7.8 Additional Design Changes

7.8.1 Beryllium Pendulum

After the program had been in progress for a period of time it became apparent that a substitution of a different epoxy for the one used to bond the springs to the pendulum assembly would not by itself eliminate the large bias shifts caused by sterilization. It was realized that the differential thermal expansion between the aluminum pendulum assembly and the stainless steel base plate due to temperature changes of 200°F (room to 275°F) creates undesirable bending stresses in the spring and shearing stresses in the epoxy joint. Calculations indicated that the differential thermal expansion between the pendulum assembly and the base plate could be reduced by a factor of 40, if the pendulum assembly were made of beryllium. Subsequently, a beryllium pendulum frame was designed. The fifth accelerometer built as part of this program utilized a beryllium pendulum.

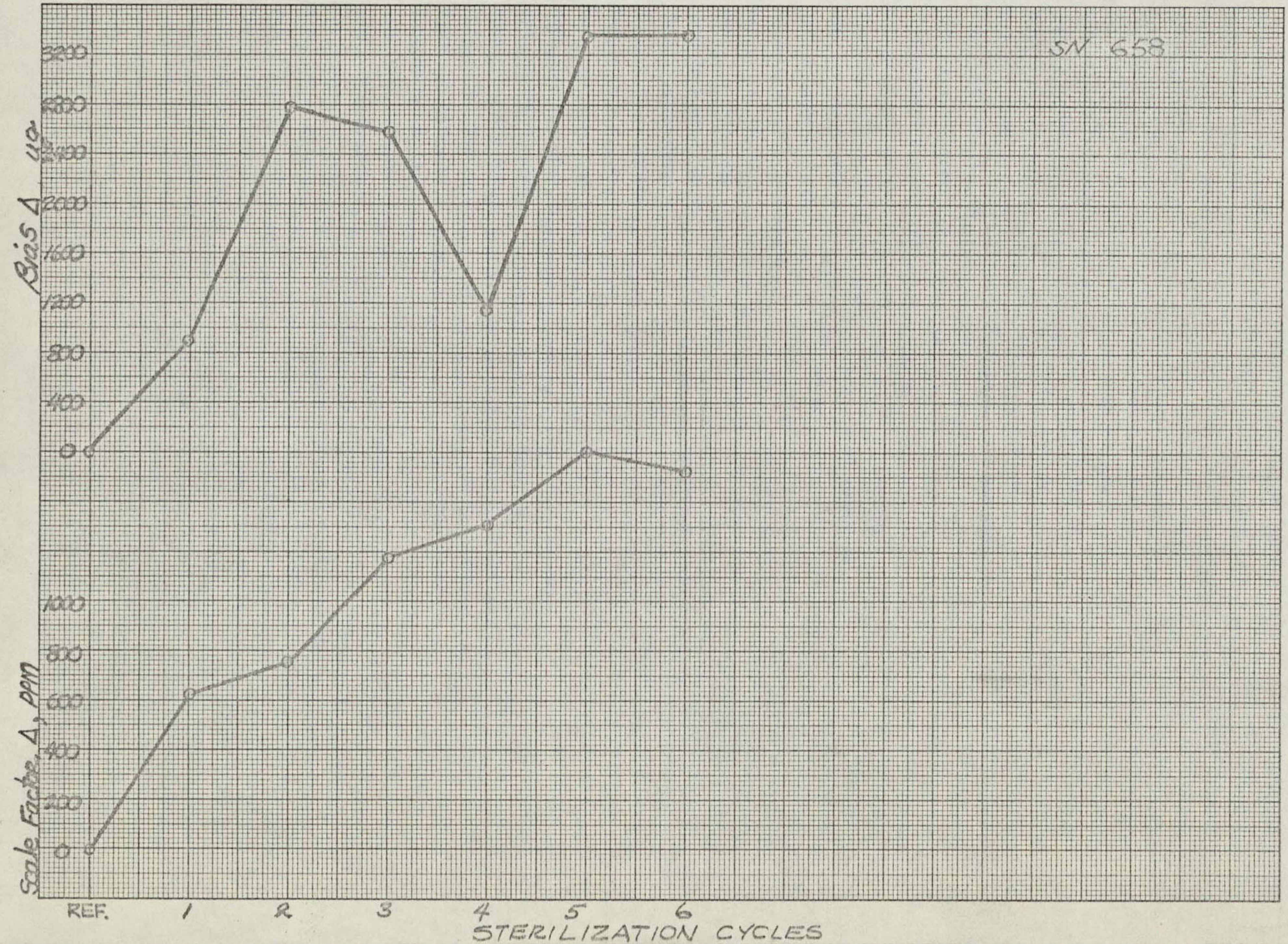
Test results did not show the bias improvement expected. The test results indicated that matching the coefficients of expansion of the base plate and pendulum did not relieve the permanent deformation due to temperature exposure. It, therefore, must be assumed that the stresses causing the permanent deformation occur either in the epoxy bonding material or in the spring material itself. The following curve and table show test results of S/N 658 with the beryllium

SUMMARY OF TEST RESULTS ON ACCELEROMETER S/N 658

Sterilization Cycle Number	1	2	3	4	5	6	7	8	9	10	11	12	Δ_{mean}	$\Delta_{1\sigma}$
Bias Change (ug)	898	1899	-213	-1440	2224	-16							559	1032
Scale Factor Change (PPM)	622	132	425	132	302	-84							225	228
Misalignment Angle Change (sec)														

Sterilization Cycle Number														
Bias Change (ug)														
Scale Factor Change (PPM)														
Misalignment Angle Change (sec)														

Bell Model VIIB-16 Accelerometer



pendulum. Test data was accumulated and is displayed as described in paragraph 7.7.1.

7.8.2 Laser Beam Welded Proof Mass

Further pursuit of this problem of pendulum design leads to consideration of different attachment techniques of the springs to the pendulum - other than with epoxy - and different spring materials. One such activity was the attachment of the springs to the pendulum utilizing laser beam welding. This technique had to be investigated in great detail because of its radical departure from BAC's previous experience. Considerable work had to be done to apply the existing laser beam welding techniques to this application. It was quickly appreciated that for proper spot welds, the critical parameters were the energy levels, pulse duration, weld spot diameter and weld spot depth. Sufficient access to the welding location had to be made available for the required fixturing. With the aid of JPL and NASA/Ames Research Center, the initial investigation, discussions and experiments were conducted in laser beam welding techniques at Optics Technology, Inc. of Palo Alto, California.

After initial experimentation with sample parts during the first phase of this activity, confidence was gained that such a technique was feasible. With the recommendations of Optics Technology Inc., Bell selected Laser Systems Corporation of Ann Arbor, Michigan, as a vendor to be used in the

actual fabrication of the pendulums. Their Laser Beam Welder Model LW 212, with a Neodymium doped glass rod head, was used in our welding operations.

The second phase included building a relatively crude pendulum which utilized a split bobbin as a single turn for current conduction. This eliminated the need for the laser welded joint to give electrical isolation of the torquer coil from the springs. This pendulum assembly was evaluated in an accelerometer, but, unfortunately, the high scale factor (120 ma/g) compromised the usefulness of the results. The final phase of this activity was to design a pendulum assembly with the proper scale factor and dynamic characteristics required by the JPL specification.

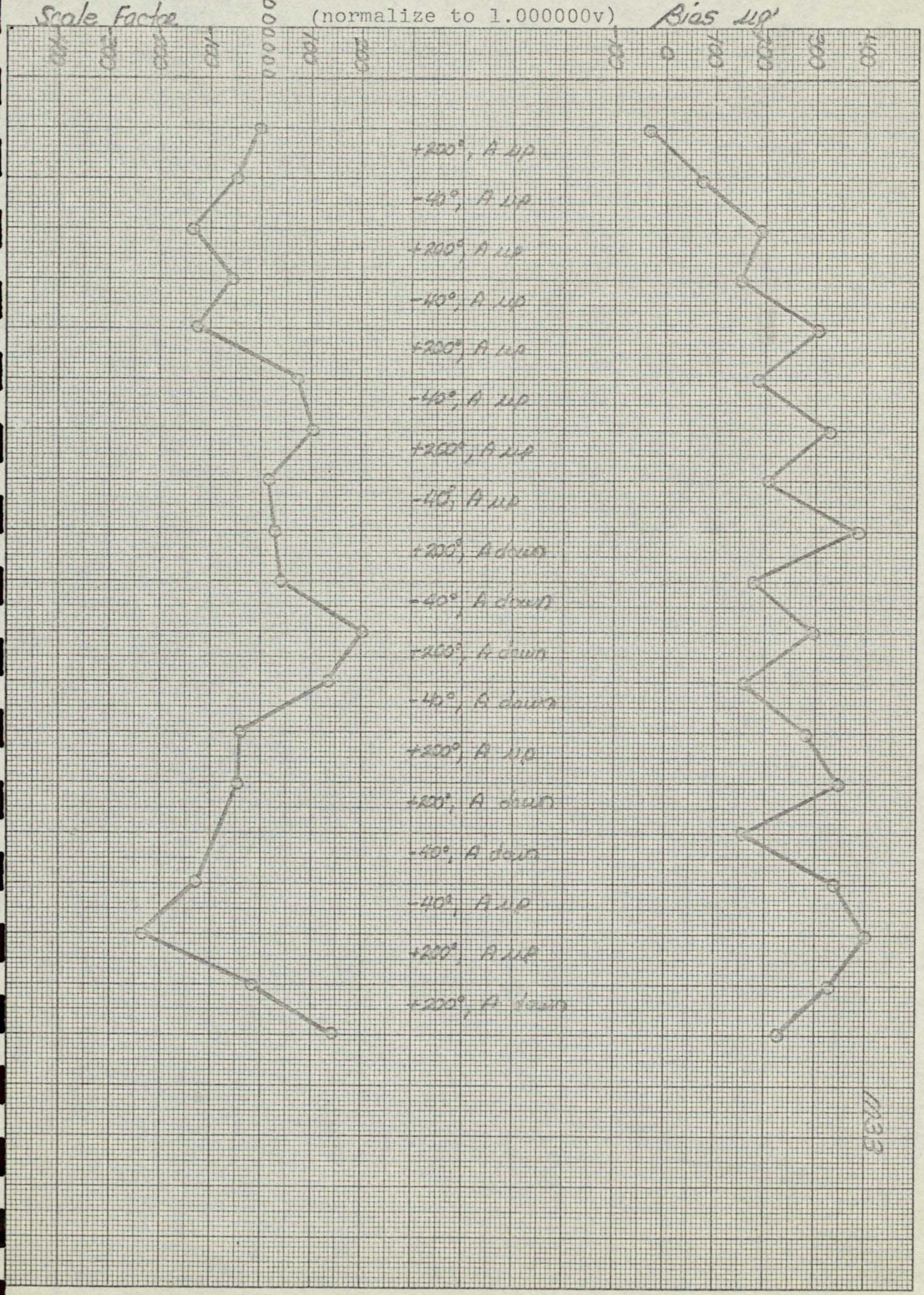
The torquer coil wire was wound directly on a standard anodized coil form and the windings secured by No. 828/Z epoxy in the same manner as on the proof mass assemblies in the five previous sterilizable accelerometers. In order to retain the use of the springs as current conductor elements, an insulating member was introduced into the electrical path between the two springs. This was achieved by constructing the aluminum supports with two overlapped parts secured together by brass fillester head screws. The contact surfaces of these parts have been hard-coat anodized 0.002 inches thick to assure the required insulation. Three proof mass assemblies of the final design were delivered to JPL. These

were primarily weld evaluation units and were not installed in instruments.

One pendulum assembly was built into a functional accelerometer and the effects of hot (200°F) and cold (-40°F) temperature soak on null bias and scale factor stability at ambient temperature were tested and evaluated. The results compared to data collected on standard Model VII accelerometers under the same test condition showed a reduction of the null bias bandwidth by at least a factor of two. The following curve shows actual test results of 18 temperature exposures (+200°F or -40°F). All bias and scale factor readings were taken at room temperature after the accelerometer was allowed to stabilize. The notations of "pin A up" and "pin A down" indicate that the sensitive axis was always sensing 1g either plus or minus (A up +1g; A down -1g). The accelerometer was not constrained during temperature exposure. The results show the bias bandwidth repeatability with temperature has been decreased by a factor of two. It also shows that the bias repeatability is not position (+1g or -1g) dependent.

7.8.3 Transformerless Electronics Assembly

A transformerless bridge pickoff electronics was developed for the Bell Model IX accelerometer. This design utilized discrete components and commercially available integrated circuits.



(7.8.2)

Bell Model VIIB Accelerometer

A matched pair of Amelco 2N3922 field effect transistors are used in conjunction with a UA709 operational amplifier. The A-C gain setting is about 100. See Schematic, Fig.7.8.3.

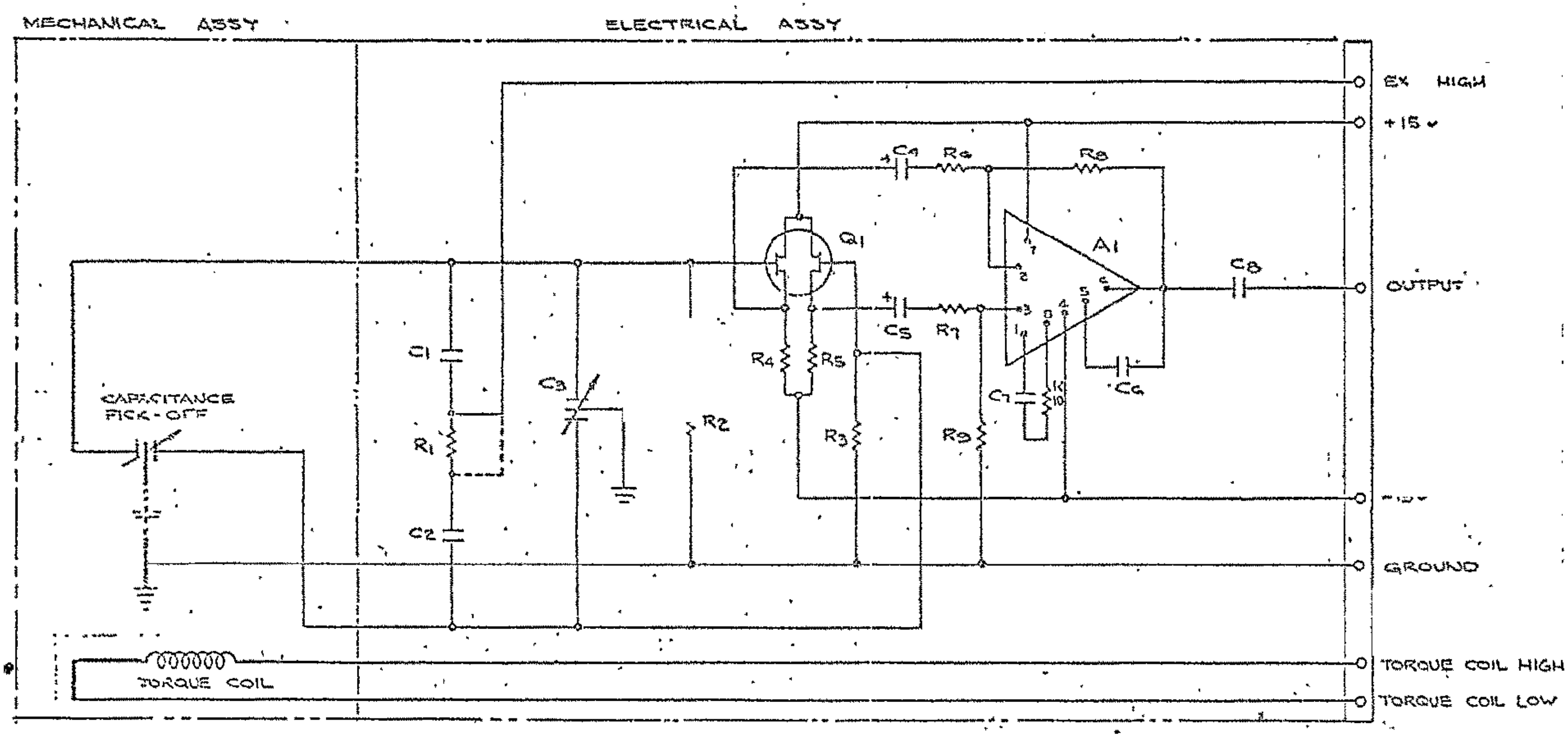
The evaluation of the new design concept brought BAC to the following conclusions:

1) The 19 pf input capacitances of the matched pair FET devices track in temperature extremely well;
2) The null drift of the electronics was found to be 0.0008 pf/°F, which is well within the internal specification Bell set for bonnet null drift.
3) This design gives better electrical null stability because it minimizes undesired stray capacitances in the critical bridge area and improves their stability, because the input capacitance stability of FET devices is superior to stray capacitances of hand wound transformer windings.

The results encouraged BAC to recommend the design principle for other programs, including the sterilizable Model IIB accelerometer.

BAC built two transformerless electronic (bonnet) assemblies under the sterilization contract, of which one was evaluated under the sterilization environment.

The evaluation of the pickoff electronics in sterilization temperature shows that the D-C output did not exceed a



SCHEMATIC OF TRANSFORMERLESS PICKOFF CIRCUIT

Figure 7.8.3

bandwidth of 0.22 VDC which is equivalent to 11 ug's.

Tests were conducted with the bonnet mounted on two magnet housing assemblies with their capacitance rings connected to the bonnet, and the complete assembly enclosed in a standard Model VIIB lower cover (can).

External test electronics consisting of a reference oscillation, demodulator and a D-C amplifier were attached to the bonnet. Only the bonnet and its mounting structure was subjected to the 275°F temperature. The test electronics were held at room ambient. Initially, the variable capacitor (see Schematic Fig. 7.8.3) was adjusted to reduce the D-C offset voltage to the millivolt range. The pickoff electronics had a gain equivalent to 2000v RMS/rad; the test electronics had a gain of 50 Vdc/Vrms, thus providing a total open loop gain of 100,000 Vdc/rad. An observed change of 1 volt D-C at the output can be related to an electrical null angle change of 10 urad., which is equivalent to 50 ug's bias, assuming a spring rate of 5g/rad.

The following shows the results of six (6) exposures to 275°F for 16 hours duration each time. All readings were taken at room ambient after the bonnet had been allowed to stabilize in temperature.

Bonnet Output Repeatability

Date	Output Volts DC
1-20-70	+.035 (reference)
1-21-70	-.130
1-22-70	-.180
1-23-70	-.180
1-26-70	-.180
1-27-70	-.185
1-28-70	-.132

7.8.4 Other Spring Materials

While this design effort and testing was outside the JPL sterilization contract, BAC feels the technological advances made are pertinent to any future use or requirement for a sterilizable accelerometer. All past test results to date have indicated that the spring still contributes a large portion of bias non-repeatability in high temperature exposure. Therefore, BAC investigated various materials to replace the beryllium copper now in use in all BAC accelerometers. Elgiloy, a material manufactured by Elgin Watch Company, was selected for use as a spring material. Elgiloy has high strength characteristics in yield and elastic modules, and has been used in similar electro-mechanical applications.

Accelerometers Model VIIB S/N 303-1C and S/N 303-4 were built with Elgiloy springs. While the shape of the spring

cutout area and initial material thickness were not optimum, a spring constant of 2.5 g/rad was achieved. Initial stability tests for both instruments showed good stability. Several subjections to sterilization cycle were performed over a 26 day period. After initial changes in bias, both accelerometers tested showed a bias repeatability bandwidth of approximately 200 ug, part of which appears to be a bias drift characteristic. These first results indicate an improvement in bias repeatability by a factor of 3 or 4. Tests also indicate that sensitive axis orientation (Pin A up and Pin A down) has no direct bearing on the bias repeatability.

8.0 CONCLUSIONS AND RECOMMENDATIONS

The following conclusions can be made based on the results achieved during the program:

1) An instrument that will operate reliably after sterilization was developed.

2) The following performance parameters identified in the JPL performance objectives - scale factor, stability of 0.05% 1 sigma (in four of the five cases), input axis stability of 30 arc sec 1 sigma - were successfully demonstrated after sterilization.

3) The design changes implemented as part of the program reduced the bias uncertainty after sterilization to well below that demonstrated by standard Model VII's, but the performance objective was not achieved.

The laser beam welded pendulum was not fully evaluated under the contract, but was subsequently evaluated as part of an in-house effort. The preliminary results indicate a bias repeatability improvement by a factor of two.

Additional in-house efforts with new spring material (still using epoxy bonding of the spring to the pendulum) also have shown improved post sterilization bias repeatability.

Therefore, it is the recommendation of BAC at this time

that accelerometers should be built and evaluated with laser beam welding of the spring to the pendulum, utilizing the new spring material. Based on the results to date, such a combination will have a greater likelihood of achieving the desired post sterilization repeatability.

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10.0 APPENDIX

This appendix contains computer print-outs of actual data obtained from accelerometers tested under this program: temperature, output at +1g, output at -1g, scale factor (volts and MA/G), bias, slope of scale factor and bias between temperatures indicated.

The following defines computer print-out headings:

T	-	Stabilized temperature of data points
V90	-	+1g output
V270	-	-1g output
S.F.	-	Scale Factor derived from 90-270° outputs
MA/G	-	Current Sensitivity
B(ug)	-	Bias derived from 90-270° outputs
PPM/°F	-	Scale Factor slope between temperatures indicated in T
B(ug/F)	-	Bias slope between temperatures indicated in T

ACCELEROMETER S/N 0657
INITIAL TESTING

T(I)	V90(I)	V270(I)	SF(I)	MA/G	B(UG)	PPM/F	B(UG/F)
73.18	-1.047512	1.046787	1.047150	0.910565	-346.1	0.0	0.0
123.55	-1.052648	1.052487	1.052567	0.915276	-76.1	103.2	5.4
150.08	-1.055401	1.055599	1.055500	0.917826	84.0	105.9	6.6
175.06	-1.058098	1.058640	1.058373	0.920325	260.4	110.2	6.7
73.00	-1.047429	1.046758	1.047093	0.910516	-320.6	104.4	5.7
125.06	-1.052790	1.052679	1.052734	0.915421	-52.5	104.0	5.1
148.32	-1.055263	1.055470	1.055366	0.917709	98.0	105.9	6.4
175.57	-1.058105	1.058680	1.058392	0.920340	271.7	107.5	6.6
71.20	-1.047247	1.046570	1.046908	0.910355	-323.4	103.9	5.7
122.33	-1.052526	1.052428	1.052477	0.915197	-46.7	103.5	5.6
150.46	-1.055475	1.055721	1.055598	0.917911	116.5	108.2	5.9
175.69	-1.058154	1.058749	1.058452	0.920393	281.1	108.3	6.5
71.78	-1.047323	1.046630	1.046976	0.910414	-333.1	104.3	5.9
122.58	-1.052520	1.052338	1.052428	0.915155	-26.5	103.0	4.8
147.83	-1.055180	1.055366	1.055272	0.917628	88.1	107.9	6.9
175.24	-1.058146	1.058703	1.058424	0.920368	263.6	110.2	6.4
74.23	-1.047577	1.046913	1.047245	0.910648	-316.9	104.6	5.7
122.83	-1.052575	1.052429	1.052502	0.915219	-60.8	103.8	5.1
148.64	-1.055280	1.055470	1.055374	0.917717	89.9	106.6	6.2
176.22	-1.058223	1.058833	1.058528	0.920459	288.3	109.6	7.2

Date
Model

BELL AEROSYSTEMS
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Report
Page

BAC 0345 Rev. 1248

ACCELEROMETER S/N 0657

PARAMETER CHECH AFTER EACH STERILIZATION CYCLE - SECOND PERIOD

T(I)	V90(I)	V270(I)	SF(I)	MA/G	B(UG)	PPM/F	B(UG/F)
72.00	-1.048809	1.045737	1.047318	0.910711	-1509.3	101.6	17.2
122.36	-1.054960	1.051660	1.052850	0.915530	1139.9	105.6	7.3
148.55	-1.056746	1.054832	1.055789	0.918077	-906.0	107.1	8.9
175.77	-1.059629	1.058359	1.058994	0.920864	-590.8	112.8	11.3
73.04	-1.047199	1.047745	1.047472	0.910845	260.4	105.9	-8.4
123.57	-1.052425	1.053512	1.052968	0.915624	515.8	104.4	5.1
148.64	-1.055025	1.056520	1.055772	0.918062	707.7	107.1	7.7
174.70	-1.057745	1.059673	1.058709	0.920617	910.2	107.9	7.8
72.68	-1.046766	1.048115	1.047441	0.910838	643.7	104.3	2.6
122.11	-1.051869	1.053829	1.052849	0.915521	930.7	105.0	5.8
148.24	-1.054560	1.056931	1.055745	0.918030	1123.3	106.1	7.4
175.71	-1.057460	1.060309	1.058885	0.920769	1345.6	109.4	8.1
72.61	-1.048513	1.046397	1.047455	0.910830	1010.2	104.7	12.8
122.14	-1.053547	1.052174	1.052860	0.915531	-652.2	104.7	7.2
149.50	-1.056290	1.055444	1.055863	0.918145	-400.6	105.2	9.2
177.10	-1.059108	1.058880	1.058993	0.920864	-107.6	108.1	10.6
72.95	-1.047045	1.048036	1.047540	0.910904	472.9	103.7	-5.6
122.90	-1.052135	1.053723	1.052929	0.915590	754.0	103.5	5.6
148.95	-1.054810	1.056829	1.055820	0.918104	956.5	106.2	7.8
175.12	-1.057541	1.059990	1.058763	0.920666	1156.6	107.8	7.6
73.40	-1.048568	1.046610	1.047588	0.910946	-934.5	103.9	10.6
122.50	-1.053528	1.052219	1.052874	0.915542	-621.4	103.4	6.4
150.28	-1.056328	1.055539	1.055933	0.918202	-373.5	105.4	8.9
176.90	-1.058951	1.058784	1.058867	0.920754	-78.8	105.5	11.1

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ENDRUN

MECHANICAL UNIT S/N 3 JPL S/N 0658

TEMPERATURE RUN 2

T(I)	V90(L)	V270(I)	SF(I)	MA/G	B(UG)	PM/F	(UG/F)
72.37	-1.048303	1.048779	1.048540	0.911774	226.9	0.0	0.0
122.70	-1.053530	1.054438	1.053984	0.916507	430.7	103.7	4.0
147.15	-1.056129	1.057289	1.056709	0.918878	548.7	106.6	4.8
176.22	-1.059324	1.060686	1.060005	0.921744	642.4	108.5	3.2
72.09	-1.048420	1.048679	1.048550	0.911782	123.7	103.8	5.0
122.32	-1.053623	1.054308	1.053966	0.916492	324.8	103.3	4.
150.08	-1.056549	1.057566	1.057057	0.919180	480.9	106.5	5.
174.27	-1.059188	1.060402	1.059794	0.921560	572.8	108.2	3.
72.55	-1.048380	1.048608	1.048493	0.911733	108.7	104.8	4.
122.34	-1.053555	1.054199	1.053877	0.916414	305.4	103.6	4.
150.58	-1.056705	1.057675	1.057190	0.919296	458.7	112.3	5.
176.18	-1.059449	1.060550	1.059999	0.921738	519.1	104.9	2.
72.34	-1.048425	1.048499	1.048462	0.911706	35.5	104.8	4.
120.74	-1.053507	1.053974	1.053741	0.916296	221.7	104.5	3.
150.55	-1.056657	1.057505	1.057080	0.919200	401.0	107.2	6.
176.00	-1.059423	1.060501	1.059962	0.921706	508.3	108.3	4.
73.33	-1.048512	1.048586	1.048549	0.911781	35.5	104.9	4.
122.00	-1.053630	1.054087	1.053858	0.916398	216.7	104.5	3.
149.31	-1.056537	1.057361	1.056949	0.919086	389.8	108.3	6.
175.55	-1.059438	1.060521	1.059979	0.921721	511.0	110.5	4.
73.04	-1.048361	1.048527	1.048444	0.911690	79.1	106.1	4.
120.72	-1.053446	1.053964	1.053704	0.916264	245.7	105.7	3.
150.42	-1.056602	1.057490	1.057046	0.919170	420.0	107.6	5.
175.21	-1.059378	1.060490	1.059934	0.921681	524.6	111.4	4.
72.90	-1.048072	1.050121	1.049096	0.912257	976.8	99.9	-4.
176.00	-1.059047	1.061913	1.060479	0.922156	1351.2	106.4	3.
72.82	-1.046217	1.052253	1.049234	0.912378	2876.3	102.7	14.
175.08	-1.057341	1.064079	1.060710	0.922356	3176.5	108.1	2.
75.22	-1.046885	1.052475	1.049680	0.912765	2662.9	104.1	5.
176.92	-1.057837	1.064078	1.060957	0.922571	2941.6	106.8	2.
74.35	-1.048534	1.051103	1.049818	0.912885	1223.2	102.4	16.
177.75	-1.059283	1.062958	1.061120	0.922713	1731.4	105.2	4.
75.25	-1.046515	1.053755	1.050135	0.913160	3447.3	101.0	16.
175.98	-1.057480	1.064859	1.061170	0.922756	3477.1	105.4	0.
74.48	-1.046444	1.053650	1.050047	0.913084	3431.3	103.3	0.
174.74	-1.057894	1.064750	1.061321	0.922888	3229.9	108.2	-2.

STERILIZATION

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M.0072 BEGIN

BELL AEROSYSTEMS CO
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MECHANICAL UNIT S/N 659 JPL STERILIZATION TESTING

INITIAL TESTING

T(I)	V90(I)	V270(I)	SF(I)	MA/G	B(UG)	PPM/F	B(UG/F)
72.18	1.045437	-1.045707	1.045571	0.995782	-129.1	0.0	0.0
121.64	1.050830	-1.051550	1.051189	1.001132	-342.5	109.2	-4.3
148.91	1.053823	-1.054872	1.054347	1.004140	-497.0	111.1	-5.7
177.44	1.057076	-1.058451	1.057763	1.007393	-649.6	114.9	-5.3
72.75	1.045580	-1.045870	1.045725	0.995928	-138.6	108.7	-4.9
123.04	1.051020	-1.051804	1.051412	1.001344	-372.8	108.7	-4.7
148.42	1.053842	-1.054879	1.054360	1.004152	-492.1	111.4	-4.7
176.45	1.057010	-1.058370	1.057690	1.007323	-642.9	114.0	-5.4
71.78	1.045477	-1.045747	1.045611	0.995820	-129.1	109.1	-4.9
122.92	1.050997	-1.051783	1.051390	1.001323	-373.7	108.6	-4.8
149.09	1.053869	-1.054943	1.054406	1.004196	-509.2	110.5	-5.2
175.96	1.056910	-1.058271	1.057590	1.007229	-643.8	113.7	-5.0
71.78	1.045500	-1.045788	1.045644	0.995851	-137.7	108.4	-4.9
121.78	1.050843	-1.051661	1.051252	1.001192	-389.2	107.8	-5.0
149.81	1.053975	-1.055045	1.054510	1.004294	-507.4	111.5	-4.2
177.04	1.057032	-1.058415	1.057723	1.007355	-654.1	113.2	-5.4
71.38	1.045447	-1.045733	1.045590	0.995800	-136.8	108.5	-4.9
121.57	1.050858	-1.051649	1.051253	1.001193	-376.5	108.5	-4.8
148.89	1.053849	-1.054915	1.054382	1.004173	-505.6	109.8	-4.7
175.96	1.056908	-1.058284	1.057595	1.007233	-650.6	113.9	-5.4
72.09	1.045506	-1.045806	1.045655	0.995862	-143.6	108.7	-4.9
121.78	1.050881	-1.051647	1.051264	1.001203	-364.2	108.5	-4.4
149.00	1.053869	-1.054946	1.054407	1.004197	-510.6	110.7	-5.4
175.21	1.056783	-1.058165	1.057473	1.007117	-653.4	112.2	5.4

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PARAMETER CHECK AFTER EACH STERILIZATION CYCLE - FIRST PERIOD

75.38	1.045371	-1.047323	1.046347	0.996520	-932.9	105.4	2.8
176.07	1.056179	-1.058915	1.057547	1.007187	-1293.6	107.5	-3.8
76.50	1.045223	-1.047299	1.046261	0.996439	-992.2	107.2	-3.0
175.50	1.056299	-1.058955	1.057627	1.007263	-1255.6	111.0	-2.7
76.86	1.046508	-1.045941	1.046225	0.996404	270.7	109.3	-15.5
175.82	1.057446	-1.057721	1.057583	1.007221	-130.3	110.9	-4.1
76.53	1.045732	-1.046523	1.046127	0.996312	-378.3	109.1	2.5
175.46	1.056919	-1.058359	1.057639	1.007275	-680.8	112.5	-3.1
76.06	1.046409	-1.045862	1.046135	0.996319	261.2	109.4	-9.5
176.83	1.057663	-1.058138	1.057900	1.007524	-224.5	112.9	-4.8
72.00	1.046645	-1.044820	1.045732	0.995936	872.8	109.7	-10.5
176.74	1.058425	-1.057249	1.057837	1.007463	555.8	111.8	-3.0

PARAMETER CHECK AFTER EACH STERILIZATION CYCLE - SECOND PERIOD

71.58	1.046579	-1.045008	1.045794	0.995994	751.4	108.2	-1.9
122.77	1.052190	-1.050650	1.051419	1.001351	732.4	105.6	-0.4
150.44	1.055200	-1.053869	1.054534	1.004317	630.8	107.9	-3.7
174.92	1.057890	-1.056791	1.057341	1.006990	519.5	109.9	-4.5
71.78	1.046623	-1.044873	1.045748	0.995950	836.7	106.3	-3.1
121.96	1.052163	-1.050610	1.051386	1.001319	738.8	108.0	-2.0
149.00	1.055187	-1.053822	1.054504	1.004290	647.5	110.6	-3.4
175.10	1.058166	-1.056979	1.057572	1.007211	560.9	112.7	-3.3
71.49	1.046995	-1.044565	1.045780	0.995981	1161.8	107.6	-5.8
121.68	1.052535	-1.050176	1.051355	1.001290	1122.1	106.7	-0.8
148.42	1.055510	-1.053326	1.054418	1.004207	1035.6	109.8	-3.2
176.32	1.058605	-1.056660	1.057632	1.007268	919.7	110.5	-4.2
71.71	1.049339	-1.042060	1.045699	0.995904	3480.6	107.8	-24.5
120.88	1.054730	-1.047650	1.051190	1.001133	3367.6	107.3	-2.3
147.78	1.057565	-1.050808	1.054186	1.003986	3204.7	106.8	-6.1
173.00	1.060646	-1.054268	1.057457	1.007101	3015.8	111.2	-6.7
72.18	1.048087	-1.043316	1.045701	0.995906	2281.4	107.0	7.1
122.14	1.053706	-1.049041	1.051373	1.001307	2218.7	109.1	-1.3
148.14	1.056589	-1.052172	1.054380	1.004171	2094.8	110.9	-4.8
175.96	1.059772	-1.055550	1.057660	1.007295	1995.9	113.1	-3.6
72.50	1.048530	-1.042822	1.045675	0.995881	2729.2	109.5	-7.1
122.09	1.054170	-1.048473	1.051321	1.001258	2709.1	109.4	-0.4
148.40	1.056884	-1.051410	1.054147	1.003949	2596.5	102.7	-4.3
174.74	1.059730	-1.054482	1.057106	1.006767	2481.8	108.0	-4.1

ACCELEROMETER S/N 0660
INITIAL TESTING

T(I)	V90(I)	V270(I)	SF(I)	[illegible]	B(UG)	PPM/F	B(UG/F)
72.68	-0.963078	0.962840	0.962950	0.917104	-123.6	0.0	0.0
121.71	-0.968208	0.967778	0.967993	0.921898	-222.1	107.2	-2.0
149.94	-0.971120	0.970740	0.970930	0.924605	-195.7	108.3	0.9
174.78	-0.973804	0.973408	0.973606	0.927243	-203.4	112.2	-0.3
72.58	-0.963082	0.962839	0.962960	0.917105	-120.2	107.1	-0.8
122.41	-0.968270	0.967850	0.968060	0.921961	-216.9	107.0	-1.8
149.29	-0.971090	0.970660	0.970875	0.924643	-221.4	109.1	-0.2
175.23	-0.973841	0.973408	0.973624	0.927261	-222.3	110.5	-0.0
71.02	-0.962923	0.962673	0.962798	0.916950	-129.9	106.7	-0.9
122.07	-0.968260	0.967820	0.968040	0.921943	-227.3	107.2	-1.9
149.63	-0.971139	0.970696	0.970917	0.924683	-228.1	108.7	-0.0
174.49	-0.973824	0.973380	0.973602	0.927240	-228.0	112.5	0.0
71.56	-0.962993	0.962726	0.962859	0.917009	-138.6	107.2	-0.9
123.30	-0.968372	0.967922	0.968147	0.922044	-232.4	106.7	-1.8
149.00	-0.971050	0.970624	0.970837	0.924606	-219.4	109.0	-0.5
176.65	-0.973980	0.973530	0.973755	0.927386	-231.9	109.9	-0.4
73.65	-0.963197	0.962934	0.963065	0.917205	-136.6	106.6	-0.9
122.22	-0.968291	0.967807	0.968049	0.921951	-250.0	107.1	-2.3
148.59	-0.971030	0.970576	0.970803	0.924574	-233.9	108.8	0.6
174.60	-0.973808	0.973355	0.973581	0.927229	-232.0	111.3	0.0

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ACCELEROMETER S/N 0660

PARAMETER CHECK AFTER EACH STERILIZATION CYCLE - SECOND PERIOD

T(I)	V90(I)	V270(I)	SF(I)	MA/G	B(UG)	PPM/F	B(UG/F)
71.87	-0.965750	0.960635	0.963193	0.917327	-2654.7	103.8	23.6
122.45	-0.970989	0.965760	0.968374	0.922261	-2609.0	106.9	-0.9
147.81	-0.973820	0.968568	0.971194	0.924946	-2793.9	115.8	-0.2
176.72	-0.976790	0.971654	0.974222	0.927830	-2655.0	109.0	2.4
73.18	-0.965389	0.961247	0.963318	0.917446	-2149.9	108.1	-4.7
122.22	-0.970558	0.966072	0.968315	0.922204	-2516.4	106.3	-3.4
148.82	-0.973294	0.968872	0.971083	0.924840	-2276.8	109.3	1.5
175.30	-0.976070	0.971730	0.973900	0.927523	-2228.2	110.4	1.8
72.79	-0.964544	0.962086	0.963315	0.917442	-1275.3	105.9	-9.3
122.05	-0.969713	0.966994	0.968353	0.922247	-1493.9	106.7	-2.6
148.40	-0.972478	0.969720	0.971099	0.924850	-1420.1	108.2	-0.6
176.09	-0.975442	0.972661	0.974051	0.927668	-1427.6	111.3	-0.3
72.64	-0.965122	0.961430	0.963276	0.917496	-1916.4	106.9	4.7
122.29	-0.970350	0.966462	0.968406	0.922221	-1997.4	107.8	-1.8
148.71	-0.973146	0.969268	0.971207	0.924959	-1996.5	110.4	0.4
175.96	-0.976022	0.972240	0.974131	0.927743	-1941.2	111.7	2.9
72.97	-0.962782	0.963958	0.963370	0.917495	610.4	107.2	-24.8
122.94	-0.968114	0.968836	0.968475	0.922357	372.7	105.6	-4.8
149.00	-0.970908	0.971516	0.971212	0.924963	313.0	109.3	-2.3
175.10	-0.973708	0.974147	0.973927	0.927549	225.4	108.3	-3.4
73.49	-0.964383	0.962436	0.963409	0.917533	-1010.5	106.3	-12.2
122.68	-0.969700	0.967270	0.968485	0.922366	-1254.5	107.6	-5.0
148.39	-0.972420	0.969950	0.971185	0.924938	-1271.7	109.3	-0.7
176.07	-0.975493	0.972960	0.974181	0.927792	-1253.9	112.7	0.6